Development of Analytical Techniques for Wave Propagation Over Large Rough Surfaces

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LONG TERM GOALS

The long terms goals of the project are to develop analytical or efficient numerical schemes for determining the RF signal received over a rough ocean surface and in atmospheric ducting conditions.

OBJECTIVES

The objectives of the proposed work are to develop techniques for treating radiowave propagation over an electrically large rough surface. Both analytical and numerical techniques were looked at in this project.

APPROACH

One graduate Ph.D. student, Zhiguo Lai, was fully supported through the grant to help carry out the current research work. Recently an approximate analytical technique was developed for determining the mean field over a rough surface. The technique was attractive to modeling over a random rough surface because it dealt with solving the mean field in terms of the mean induced current and the mean Green's function [1]. Assuming an $e^{-i\omega t}$ time dependence, where ω is the radian frequency, an integral representation of the scattered field $E_{\mathrm{sca}}(x,z)$ under parabolic approximation can be obtained as

$$E_{\mathrm{sca}}(x,z) = E_{\mathrm{tot}}(x,z) - E_{\mathrm{inc}}(x,z) = -\frac{i}{2k_0}\int_0^x G_0\left[x,z;\xi,g(\xi)\right]J(\xi)\,d\xi \tag{1}$$

where k_0 is the free-space wavenumber, $g(x)$ is the rough surface profile, $J(x)$ is the vertical derivative of the field on the surface and will be referred to as the induced surface current throughout this report, $G_0(x,z;\xi,\eta)$ is the free-space Green's function under paraxial approximation and given by

$$G_0(x,z;\xi,\eta) = H(x-\xi)\sqrt{\frac{k_0}{2\pi\, i(x-\xi)}}\exp\left[\frac{ik_0(z-\eta)^2}{2(x-\xi)}\right] \tag{2}$$

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14. ABSTRACT
The long terms goals of the project are to develop analytical or efficient numerical schemes for determining the RF signal received over a rough ocean surface and in atmospheric ducting conditions.

15. SUBJECT TERMS

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with $H(\cdot)$ being the Heaviside step function, and $E_{\text{inc}}(x,z)$ is the incident field arising from the source $f(z)$ specified at $x = 0$ and given by

$$E_{\text{inc}}(x,z) = \int_{-\infty}^{\infty} f(\eta) G_0(x,z;0,\eta) d\eta. \tag{3}$$

If we allow the general point (x,z) to lie on the surface $z = g(x)$, equation (1) becomes

$$E_{\text{inc}}[x, g(x)] = \frac{i}{2k_0} \int_0^x G_0[x, g(x); \xi, g(\xi)] J(\xi) d\xi \tag{4}$$

which is a Volterra integral equation of the first kind for the unknown surface current. In [1] it is claimed that under parabolic approximation and low grazing angles of propagation, the scattered field and the induced surface current from a rough surface are statistically independent of the local form of the surface (thus independent of the Green's functions) at a range such that the wave has traversed several correlation lengths on the surface. Under this assumption, taking the ensemble average of equations (1) and (4) gives

$$\langle E_{\text{sca}}(x,z) \rangle = -\frac{i}{2k_0} \int_0^x \langle G(x,z;\xi) \rangle \langle J(\xi) \rangle d\xi, \quad x \to \infty \tag{5}$$

$$\langle E_{\text{inc}}(x,z) \rangle = \frac{i}{2k_0} \int_0^x \langle G(x;\xi) \rangle \langle J(\xi) \rangle d\xi, \quad x \to \infty \tag{6}$$

Our objective is to verify the validity of (5) and (6) by comparing the results to those obtained by an exact approach. In the exact approach we solve (1) and (4) for each realization of a Monte Carlo approach. In the results that follow, the exact method is labeled as FSIE, while the approximate method as USM. Both are compared to an analytical method based on first ordered smoothing approximation (FOSA) [2].

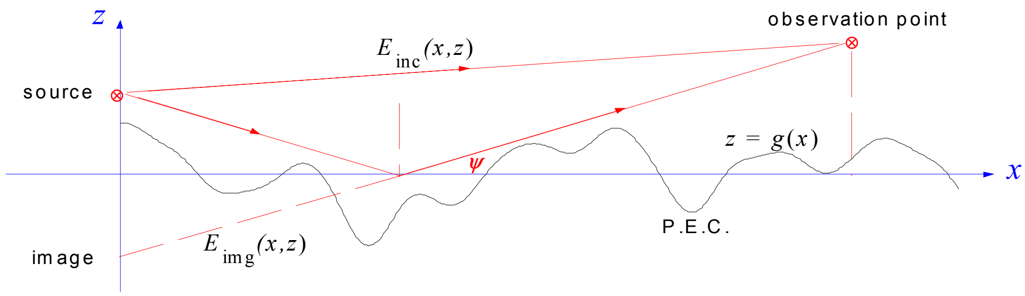

Fig. 1: An aperture antenna illuminating a one-dimensional rough surface.

WORK COMPLETED AND RESULTS

In this section, some examples are presented to numerically evaluate the effectiveness and accuracy of the above method. We consider a distributed Gaussian source of the form

$$f(z) = \frac{1}{\sqrt{2\pi}\sigma_h} \exp\left[-\frac{(z-z_0)^2}{2\sigma_z^2} \right] \tag{7}$$

where z_0 is the height of the source. The standard deviation of the source function, σ_z, can be chosen to fit the required antenna 3dB elevation beam width [9]. The incident field due to such a source is given by

$$E_{\text{inc}}(x,z) = \sqrt{\frac{k_0}{2\pi\, i(x - ik_0\sigma_z^2)}} \exp\left[\frac{ik_0(z-z_0)^2}{2(x - ik_0\sigma_z^2)} \right]. \tag{8}$$

The field due to the image source $E_{\text{img}}(x,z)$ can be obtained simply by replacing z_0 with $-z_0$ in equation (8). All calculations below were performed at a frequency of 3 GHz ($\lambda = 0.1$m). The source parameters are $z_0 = 10\lambda$ and $\sigma_z = 0.3\lambda$ corresponding to a beam width of 45º. The surface considered has a Gaussian correlation function of the form $\rho(x) = \exp(-x^2 / L_c^2)$ and the corresponding PSD is $W(k) = \sqrt{\pi}\sigma_h^2 L_c \exp(-k^2 L_c^2 / 4)$. Fig. 2 shows the scattered fields for a moderately rough surface and Fig. 3 shows the corresponding results for the equivalent admittance of the rough surface. Fig. 4 and 5 show the results for a very rough surface. It is apparent from Figs. 3 and 5 that the USM technique yields results that are less accurate than the more cumbersome FSIE technique even for the moderate rough surface. A more detailed study is performed in [3].

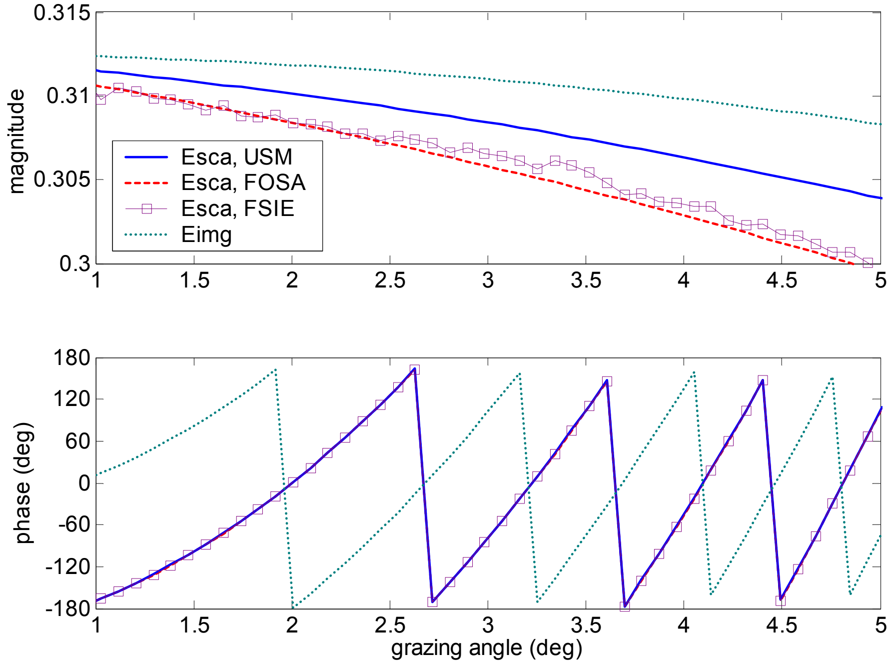

Figure 2. The mean scattered field (top: magnitude, bottom: phase) computed using USM, FOSA, and FSIE for a Gaussian rough surface with $k_0\sigma_h = 1$***,*** $L_c = 3\lambda$***, and*** $x = 1024\lambda$***.***

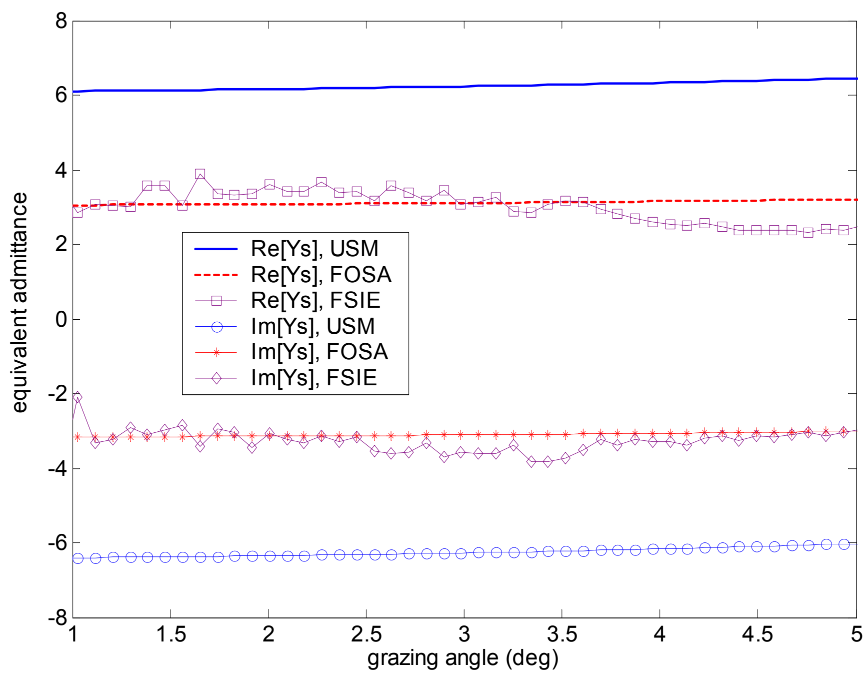

Figure 3. The equivalent admittance computed using USM, FOSA, and FSIE for a Gaussian rough surface with $k_0\sigma_h = 1$***,*** $L_c = 3\lambda$***, and*** $x = 1024\lambda$***.***

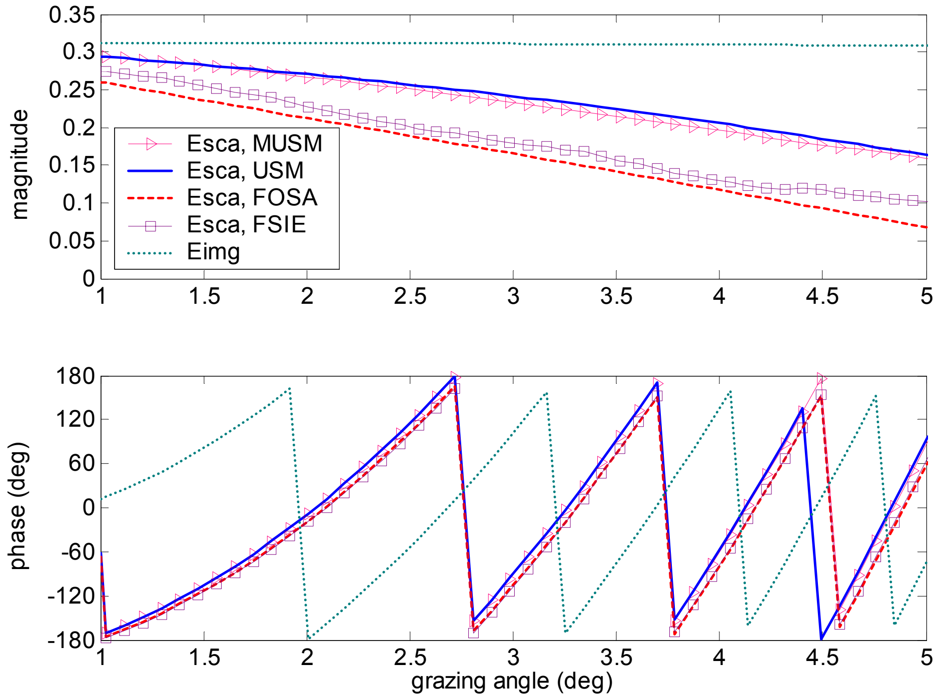

Figure 4. The mean scattered field (top: magnitude, bottom: phase) computed using MUSM, USM, FOSA, and FSIE for a Gaussian rough surface with $k_0\sigma_h = 10$***,*** $L_c = 30\lambda$***, and*** $x = 1024\lambda$***.***

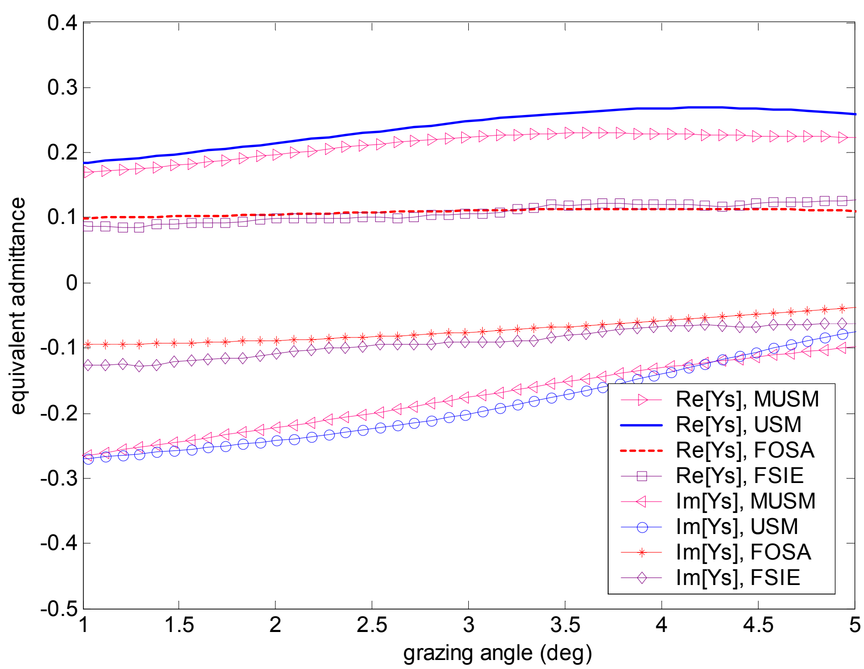

Figure 5. The equivalent admittance computed using MUSM, USM, FOSA, and FSIE for a Gaussian rough surface with $k_0\sigma_h = 10$***,*** $L_c = 30\lambda$***, and*** $x = 1024\lambda$***.***

IMPACT/APPLICATIONS

The results presented thus far and successful completion of the ongoing research should help the PE code developers in generating better operational codes for assessing the effects of ocean roughness on radar detectability and surveillance.

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[3] Z. Lai and R. Janaswamy, ``Forward Electromagnetic Wave Propagation over Random Sea Surface: A Numerical Assessment of Uscinski-Stanek's Method,''paper P71.1, *Proc. 2005 IEEE Antennas & Propagation International Symposium/URSI Meeting*, Washington, DC July 4-8, 2005.

PUBLICATIONS

Z. Lai and R. Janaswamy, ``Specular propagation over rough surfaces: numerical assessment of Uscinski and Stanek's mean Green's function technique,'' submitted to *Waves in Random and Complex Media*, June 2005.